Magnetic skeletons in Davy Jones' locker

Richard B. Frankel

MANY fossils of ancient plants and animals are embedded in sedimentary deposits but, by comparison, the fossil record for bacteria is sparse. Now, however, Petersen *et al.* on page 611 of this issue[1] and Stolz *et al.*[2] present evidence that magnetotactic bacterial microfossils litter the deep ocean sediments.

Various species of magnetotactic bacteria inhabit freshwater and marine sediments throughout the world[3]. Magnetotaxis (orientation and migration along geomagnetic field lines) is based on magnetosomes, chains of membrane-enclosed magnetite (Fe_3O_4) particles in cells. The chain of magnetosomes imparts a permanent magnetic dipole moment of the order of 10^{-12} electromagnetic units to each cell, sufficient for it to be passively oriented in the geomagnetic field at ambient temperatures. Thus magnetotactic bacteria are self-propelled magnetic compasses — as E.M. Purcell once remarked, "this is a case of the compass steering the ship."

Magnetosomes and their arrangement in the cell are a masterpiece of permanent magnet design[4]. First, magnetosomes have a narrow size distribution, typically 400–1,000 Å, which is in the permanent, single magnetic size range for Fe_3O_4. They are too small to lower their magnetostatic energy by forming magnetic domains, yet are too large to be superparamagnetic, that is, for thermally activated relaxation of their magnetic dipole moments. Second, dipole–dipole interactions between the magnetosomes in a chain cause the individual particle moments to orient parallel to each other along the chain direction. Thus the whole magnetosome chain is an elongated, permanent, single magnetic domain.

The single magnetic domain properties of the magnetosome chains can persist in sediments as magnetic microfossils after the bacteria die, making a substantial contribution to the remanent magnetization of the sediments. In their new study, Petersen *et al.*[1] report fossil magnetosome chains in deep-ocean sediments from the South Atlantic dating from 5 to 50 million years ago. The identification is primarily based on the narrow size distributions, shapes and arrangements of the magnetite particles extracted from the sediments. Magnetotactic bacteria are known to produce magnetosomes with diverse, species-specific morphologies[3,5,6] which can be distinguished from nonbiogenic magnetite. In a related paper, Stolz *et al.*[2] report living magnetotactic bacteria and magnetosome chains in the upper layers of deep-sea sediments from the Santa Barbara basin. Blakemore[7] and Kirschvink and Chang[8] previously reported magnetosome-shaped particles in sediments, but Petersen *et al.* and Stolz *et al.* now claim that magnetosomes are the primary carrier of stable magnetic remanence in deep-sea sediments.

How far back in the geological record might one expect to find magnetic microfossils? Magnetotactic bacteria are microaerophiles, requiring trace amounts of molecular oxygen for magnetosome formation[9]. Thus they currently inhabit the relatively restricted microaerobic zone in sediments. Blakemore *et al.*[9] argue that originally magnetosome formation would have been possible only in microhabitats such as algal mats where O_2 was being produced. However, as free O_2 began to accumulate in the global atmosphere about 2×10^9 years ago, the Earth's surface would have been microaerobic by today's standards and microaerophiles, including magnetotactic bacteria, might have been the most prevalent organisms. Thus they may have played a major part in the deposition of iron-rich minerals including magnetite in the widespread banded iron formations that accumulated at that time.

1. Petersen, N. Dobeneck, T.V. & Vali, H. *Nature* **320,** 611 (1986).
2. Stolz, J.F. Chang, S.B.R. & Kirschvink, J.L. *Nature* (in the press).
3. Blakemore, R.P. *A. Rev. Microbiol.* **36,** 217 (1982).
4. Frankel, R.B. *A. Rev. Biophys. Bioengng.* **13,** 85 (1984).
5. Matsuda, T. *et al. Nature* **302,** 411 (1983).
6. Mann, S. *et al. Nature* **310,** 405 (1984).
7. Blakemore, R.P. *Science* **190,** 377 (1975).
8. Kirschvink, J.L. & Chang, S.B.R. *Geology* **12,** 559 (1983).
9. Blakemore, R.P. *et al. Geomicrobiol. J.* **4,** 53 (1985).